

## **APPENDIX A**

### **Additional Information About Stainless Steel, Brass, and Bronze Alloys**

The discussions below were excerpted from the EPA document “Report on the Corrosion of Certain Alloys” [EPA report # EPA-260-R-01-002 (July 2001)], which was made available to the public in July, 2001. The interested reader should consult this report for additional and more detailed discussions on alloys, and references pertaining to alloys.

## **Stainless Steel Alloys**

### *Identification of Stainless Steel Alloys*

Stainless steels produced in the United States can be identified in three general ways: (1) by the Unified Numbering System (UNS) numbers developed by the American Society for Testing and Materials (ASTM) and the Society of Automotive Engineers (SAE) for all commercial metals and alloys; (2) by the American Iron and Steel Institute (AISI) numbering system; and (3) by the names based on compositional abbreviations, proprietary designations, and trademarks. The UNS number comprises six symbols (i.e., a letter followed by five numbers) that are difficult to recognize instantly and memorize for the 180 stainless steels. Therefore, technical journals allow each alloy to be initially identified by the lengthy UNS number and then subsequently the better-known AISI or another designation may be used. The AISI number designates the wrought standard grades of stainless steels by three-digit numbers. Three groups of wrought stainless steels, series 200, 300, and 400, have composition limits standardized by the AISI. Steels in the AISI 400 series contain a minimum of 11.5% chromium and usually not more than 2.5% of any other alloying element. Steels in the AISI 300 series contain a minimum of 16% chromium and 6% nickel; the relative amounts of these elements are balanced to give an austenitic structure. Austenitic structures have face-centered cubic lattices, while ferritic structures have body-centered cubic lattices and martensitic structures have body-centered tetragonal or cubic lattices. Stainless steels containing both austenite and ferrite, usually in roughly equal amounts, are known as duplex. Duplex stainless steels, precipitation-hardening stainless steels, and higher alloys containing less than 50% iron (Fe) do not have AISI designations and are generally known by names based on compositional abbreviations and trademarks, as well as UNS numbers.

The many grades of stainless steel are due to the crystal structure of the iron-rich matrix. The austenite field in iron exists over an increasingly small temperature range as chromium is added, and disappears at about 12% chromium. To make the martensitic grades, it is important to be able to form 100% austenite first. Fortunately carbon extends the austenite range so it is possible to have all austenite prior to quenching in a 12% chromium carbon steel, or if the carbon content is high enough, even in a 17% chromium steel. Adding several percent of nickel to an iron-chromium alloy can allow austenite to exist as metastable or stable forms down to ambient temperature. A body-centered cubic phase, or sometimes a hexagonal close-packed phase, can then form martensitically, and can give very high strengths to the stainless steel. For the ferrite grades, it is necessary to have at least 12% chromium and only very small amounts of elements that stabilize austenite. For these materials, the structure is body-centered cubic from room temperature to the melting point. Some elements, such as molybdenum, niobium, titanium, and aluminum, which encourage the body-centered cubic structure, may also be in these steels.

Compositions of some stainless steels are listed in the following table, Table A-1.

**Table A-1**

**Typical Composition of some Stainless Steels, wt%**

(Sulfur (S) and Phosphorus (P) are held below 0.03 and 0.04% max, respectively, balance is Fe)

<b>AISI #</b>	<b>C</b>	<b>Mn</b>	<b>Si</b>	<b>Cr</b>	<b>Ni</b>	<b>Mo</b>	<b>N</b>	<b>Ti</b>	<b>Nb</b>
201	0.15	6.50	0.75	17.0	4.50		0.20		
202	0.15	8.75	0.75	18.0	5.00		0.20		
205	0.12	15.0	0.50	17.0	1.75		0.35		
304	0.06	1.50	0.75	19.0	10.0				
309	0.16	1.50	0.75	23.0	13.5				
310	0.20	1.50	1.00	25.0	20.5				
316	0.06	1.50	0.75	17.0	12.0	2.50			
321	0.06	1.50	0.75	18.0	10.5			0.50	
330	0.08	2.00	1.00	18.0	35.0				
347	0.06	1.50	0.75	18.0	11.0				1.00
410	0.12	0.75	0.75	12.5					
430	0.10	0.75	0.50	16.0	0.30				
446	0.30	1.00	0.75	25.0			0.20		

## *Classes of Stainless Steel Alloys*

There are four major classes of stainless steel: 1) austenitic; 2) martensitic; 3) ferritic; and 4) age-hardened or precipitation-hardening steels. A brief description of each is provided below.

1) ***Austenitic stainless steels***, these are essentially non-magnetic and cannot be hardened by heat treatment. They are hardenable only by cold-working. As a group, these stainless steels have greater corrosion resistance than the other three groups. At the same time there is a wide range in the corrosion resistance among the austenitic types. Most of these steels contain nickel as the principal austenite former, and some contain substantial amounts, 2-4%, of manganese and less nickel. These steels possess better corrosion resistance than the straight chromium steels. Chromium content is generally between 16-26%, with the nickel content generally between 4-22%. The 300 series represents by far the largest category of stainless steels produced in the United States. For the sake of discussion, the austenitic alloys can be divided into four subclasses.

Class A: AISI types 301, 302, 303, 304, 304L, 304N, 321, 347, and 348 are all contained within class A. Each of the types in this group can be considered an 18-8 stainless steel (i.e., 18% chromium content and 8% nickel content). Within this class, there is no great difference in the general corrosion resistance of the individual types. Those that have a higher alloy content are slightly more corrosion resistant than those with a lower alloy content. Types 321, 347, and 348 are carbide stabilized with titanium and/or niobium. Although their general corrosion resistance may be no higher than types 302 or 304, they are essentially immune to sensitization and the possible attendant intergranular corrosion under specific conditions.

Class B: Only types 305 and 384 are contained within class B. These have relatively high nickel contents (12.0% and 15.0%) nominally and respectively. While they both have greater corrosion resistance than the 18-8 steels, they were principally designed for extra-deep drawing and cold heading operations, as allowed by the higher nickel content

Class C: AISI types 302B, 308, 309, 309S, 310, 310S, and 314 are examples of the class C group. Type 302B is a modified 18-8 and has a silicon addition (2.5%) that increases oxidation resistance at elevated temperatures. Type 314 represents a higher alloy version (25% chromium-20% nickel) of an 18-8 steel. It has a silicon addition that is more corrosion resistant, especially to sulfuric acid, than type 302B and also has a high resistance to scaling at elevated temperatures. Types 308, 309, 309S, 310, and 310S are all higher in chromium and nickel and are commonly called 20-11 (20% chromium-11% nickel, type 308), 24-12 (24% chromium-12% nickel, types 309 and 309S) and 25-20 (25% chromium-20% nickel, types 310 and 310S). They have a very high resistance to corrosion and oxidation at elevated temperatures.

Class D: AISI types 316, 316L, 316F, 316N, 317 and 317L are part of this class. They contain at a minimum 16% chromium and at least 2% molybdenum. The ferrite-forming influence of the molybdenum requires an increase in nickel, as an austenite former, to at least 10%. The presence of molybdenum specifically enhances corrosion resistance to chloride pitting and crevice corrosion and also increases general resistance to specific chemicals (e.g., organic acids, amines, phosphoric acid, dilute sulfuric acid).

2) ***Martensitic stainless steels***, these are iron-chromium alloys which are hardened by heat treatment. Heat treatment results in higher strength, with a corresponding proportional diminution of ductility with increasing hardness. Corrosion resistance is less than in the other two groups. In the hardened condition there may be a greater resistance to general corrosion but there is increasingly less resistance to hydrogen-induced cracking. Martensitic steels can be heat-treated to obtain high tensile strengths. The heat treatment results in higher strengths, with a corresponding proportional diminution of ductility with increasing hardness. Corrosion resistance is less than in the other two groups. In the hardened condition, there may be a greater resistance to general corrosion, but there is increasingly less resistance to hydrogen-induced cracking. Chromium content is generally between 11.5-18% with carefully controlled carbon content. Some of the AISI types that make up this group are 403, 410, 414, 416, 420, 420F, 431, 440A, 440B, and 440C.

Types 403, 410, and 416 are known as “turbine quality.” Type 403 is virtually identical to type 410, except that it is made from specially processed and rigorously inspected ingots, as is required for steam turbine blades. Both types contain just enough chromium to maintain “stainlessness” (nominally 12.5%), but there are no significant amounts of other alloying elements. Type 416 is simply 410 with the addition of free-machining additives. Although offering improved machining characteristics, there is a sacrifice in corrosion resistance.

Types 414 and 431 provide better corrosion resistance than type 410, largely because they contain a nominal amount (2.0%) of nickel. These steels have been commonly known as 12-2 (12% chromium-2% nickel) and 16-2 (16% chromium-2% nickel), respectively.

Types 420 and 420F, despite having a higher chromium content than type 410, do not have an appreciably higher corrosion resistance level. Type 420F is almost identical to type 420, except that there is an addition of sulfur to improve machinability. This results in a slight sacrifice of corrosion resistance.

Types 440A, 440B, and 440C are all high-carbon stainless steels and are sometimes called “stainless tool steels.” These types have the highest chromium range of any of the martensitic types, yet their corrosion resistance levels are among the lowest because of their higher carbon content. There is a gradual decrease in corrosion resistance from the A to C subtypes. This is due to the increase in carbon content.

3) ***Ferritic stainless steels***, these are nonhardenable steels so designated because they cannot be hardened by heat treatment. They are hardenable only by cold-working. Chromium content is generally between 11.5-27% with low carbon content. Examples of AISI types that make up this group are 405, 409, 429, 430, 430F, 434, 436, 442, and 446. As a group the ferritic stainless steels do not closely approach the austenitic types with respect to corrosion resistance. There are, however, some ferritic types that may nearly equal the corrosion resistance levels of the austenitics in some environments, but these are exceptions. One of the most interesting aspects of this group of stainless steels is their resistance to stress corrosion.

Type 405, while meeting the minimum requirements for a stainless steel, is actually relatively low in its resistance to corrosion. The carbon level is 0.08% maximum and it has a nominal chromium content of 12.5%. An addition of 0.10 to 0.30% aluminum (a powerful ferritizer) prevents the formation of any appreciable amount of austenite at any temperature. It is thus the ideal grade for welding. Of all the stainless steels, type 409 is generally considered to have the lowest degree of corrosion resistance. It contains very nearly the minimum amount of chromium to qualify as a stainless steel (10.5-11.75%) and is stabilized with titanium.

Types 430, 430F, 434, and 436 represent the old and well-known 17-chrome stainless steel grade, which is the original type 430. Type 430 shows a high resistance against attack by practically all types of atmospheres and also by many types of chemicals, notably oxidizing acids. At times, type 430 replaces the more expensive 18-8 austenitic types. Type 430F is a machinable grade of type 430. The additives contained in it reduce the corrosion resistance of the basic type 430. Type 434 has the same chromium content as type 430, but it has a nominal 1.0% molybdenum content, which adds greatly to its resistance to certain types of corrosion, notably pitting corrosion. Type 436 is essentially type 434, but it contains up to 0.70% niobium plus tantalum for carbide stabilization. Therefore, it is suited for elevated temperature applications as well as for room-temperature corrosion resistance. Types 442 and 446 are frequently called "chrome-irons." They differ in composition only in chromium content 18.0-20.0% for type 442 and 23.0-27.0% for type 446. Neither is used to any great extent for corrosion resistance at room temperatures. Their principal uses are in heat processing equipment where resistance to scaling is important. Types 442 and 446 are capable of sustained operation at temperatures of 980°C and 1095°C respectively, without experiencing destructive scaling. A need for a higher degree of weldability than that provided by type 430 resulted in the development of type 429. Both alloys have the same carbon content; however, 429 has a lower chromium content (14.0-16.0%). This carbon-chromium ratio allows type 429 to retain its ferritic status.

4) The fourth group consists of the *age-hardened or precipitation-hardening steels*. They are hardened and strengthened by solution-quenching followed by heating for substantial times at temperatures in the range of 800-1000 degrees Fahrenheit. Precipitation-hardened stainless steels can have a microstructure consisting of ferrite, martensite, or austenite depending on the heat treatment

performed. The precipitation hardening process is thought to involve the formation of very fine intermetallics that impede dislocation motion during deformation, producing higher strength. Prolonged aging cause these intermetallics to coarsen, enabling dislocations to bypass them during deformation, and their strength to begin to decline. In this condition, the material is said to be overaged. AISI types that make up this group include 630, 631, 632, 633, 634, and 660. It is generally considered that the average corrosion resistance of this group approaches that of the 18-8 austenitic grades and that it is usually superior to the corrosion resistance of the martensitic and ferritic types.

Copper is the principal hardening agent in type 630. Its corrosion resistance approaches that of types 302 and 304. In the heat treated condition, type 631 has a duplex structure. Stainless steels that have a duplex structure have a two phase microstructure that exhibits improved strength and high resistance to stress corrosion cracking. With the exception of an addition of molybdenum, type 632 is very much like type 630. There is an improvement in strength and resistance to pitting corrosion due to the addition of molybdenum.

Type 633 is also a duplex-structure grade, but has a slightly higher alloy content than types 631 and 632. Thus, its corrosion resistance is better than types 631 or 632. Type 634 is semiaustenitic (duplex), but it has an alloy content slightly less than type 633. The duplex stainless steels are currently popular for withstanding high chloride environments. These alloys have a two-phase microstructure that exhibits improved strength and high resistance to stress corrosion. Most duplex stainless steels contain high chromium (usually about 25%), low nickel (generally about 8% maximum), and 2-4% molybdenum for enhanced resistance to chloride induced phenomena and to promote general corrosion resistance, specifically pitting corrosion.

The super-austenitic stainless steels include such alloys as 904L and 254MO. These alloys have increased resistance over the austenitic stainless steels due to the addition of 6% molybdenum or other elements.

## Brass and Bronze Alloys

Brass, bronze, and other copper alloys have been widely used for centuries in many applications because of their excellent corrosion resistance. Despite the formation of the common green patina in natural environments, copper and its alloys corrode at negligible rates in unpolluted water or air and in deaerated nonoxidizing acids. Copper roofing in rural atmospheres, where there is little if any pollution, has been found to corrode at rates of less than 0.4 mm (15 mils) in 200 years. Some copper alloy artifacts have been found in nearly perfect condition, with only small amounts of corrosion on the surface, after having been buried in the earth for thousands of years.

Although classed as corrosion resistant, neither copper nor its alloys form the truly passive corrosion-resistant film that characterizes most true corrosion-resistant alloys. In aqueous environments at ambient temperatures, cuprous oxide or cupric carbonate forms the protective scale on copper and copper alloys. The film is adherent and follows parabolic growth kinetics. For the corrosion reaction to proceed, copper ions and electrons must migrate through the cuprous oxide or cupric carbonate layer. Consequently, reducing the ionic or electronic conductivity of the film by doping with divalent or trivalent cations should improve corrosion resistance. In practice alloying additions of aluminum, zinc, tin (Sn), iron, and nickel are used to dope the corrosion product films, resulting in a significant reduction in corrosion rate.

Copper alloys can be quite susceptible to stress-corrosion cracking. While high-zinc yellow brasses are the most susceptible to stress-corrosion cracking, small amounts of phosphorus, arsenic (As), antimony (Sb), silicon, aluminum, or nickel as constituents in other copper-base alloys render them also susceptible to stress-corrosion cracking in ammoniacal environments. Other nitrogenous environments, such as nitrite or nitrate solutions, as well as nitric acid vapors, can also cause stress-corrosion cracking. As for other elements, the corrosion-resistant behavior of copper is best revealed by considering its alloy systems. The basic systems for copper are copper-tin (bronze), copper-zinc (brass), copper-nickel (cupro-nickels), and variations of these, including aluminum-bronzes, phosphor-bronzes, and nickel-silvers.

Copper and its alloys are classified in the United States by composition according to Copper Development Association (CDA) designations which have been incorporated into the Unified Numbering System (UNS) for metals and alloys. Wrought copper materials are assigned five digit numerical designations which range from C10100 through C79999, but only the first three or sometimes four numerals are frequently used for brevity. Designations that start with 8 or 9 are reserved for cast copper alloys.

Most wrought alloys are provided in conditions that have been strengthened by various amounts of cold work or heat treatment. Cold worked alloys are the result of cold rolling or drawing by prescribed amounts of plastic deformations from the annealed condition. Alloys that respond to strengthening by heat treatment are referred to as precipitation or age hardenable. The designations and principal alloying elements of wrought copper alloys are given in Table A-2.

**Table A-2**  
**UNS (CDA) Designations for Brass and Bronze Alloys**

Alloy group	UNS (CDA) designation	Principal alloy elements
Brasses	C20500-C28580	Zn
Leaded brasses	C31200-C38590	Zn-Pb
Tin brasses	C40400-C40980	Sn, Zn
Phosphor bronzes	C50100-C52400	Sn-P
Leaded bronzes	C53200-C54800	Sn-P, Pb
Phosphorus-silver	C55180-C55284	Ag-P
Aluminum bronze	C60600-C64400	Al, Fe, Ni, Co, Si
Silicon bronze	C64700-C66100	Si, Sn
Modified brass	C66400-C69950	Zn, Al, Si, Mn

Nickel and copper are mutually soluble or miscible. In commercial alloys known as copper-nickels or cupronickels, where copper is the dominant element, the copper content ranges from about 54% to over 90%. Nickel provides the best general resistance to aqueous corrosion of all the commercially important alloy elements. It promotes resistance to impingement or erosion corrosion and to stress corrosion cracking. The addition of 10-25 wt% nickel to copper-zinc alloys produces alloys called nickel-silvers. Most commonly these have about 18% nickel and 55-65% copper. Such alloy

additions promote good resistance to corrosion in both fresh and salt waters. The nickel inhibits dezincification. Nickel-silvers are much more corrosion resistant in saline solutions than brasses of similar copper content.

Elements are added to copper alloys in varying amounts to enhance corrosion resistance. For example, the addition of arsenic, antimony, or phosphorus improves resistance of Admiralty Metals (72% copper, 26% zinc, 1% tin) to dezincification. Also, 2% aluminum is added to 76% copper-22% zinc solutions to produce aluminum brass, and a small amount of arsenic (less than 0.10%) is added to the alloy to inhibit dezincification.

Brass and bronze can be grouped according to how the principal elemental additions affect properties. This grouping depends primarily on whether the additions that dissolve in the liquid copper can form discrete second phases during melting/casting or in-process thermal treatment.

Brass and bronze are considered to be solid solution alloys when copper dissolves other elements to varying degrees to produce a single-phase alloy that is strengthened relative to unalloyed copper. The contribution to strengthening from an element depends on the amount of the element in solution and by its particular physical characteristics, such as atom size and valency. Tin, silicon, and aluminum show the highest strengthening efficiency of the common elemental additives, whereas nickel and zinc are the least efficient. The limiting factor in their alloy range is the extent to which the elements, either singly or in combination, remain dissolved in the copper during processing. Table A-3 gives the designations and compositions of some specific brass and bronze wrought alloys. More details on these specific alloys are provided below.

**Table A-3**  
**UNS (CDA) Designation and Compositions of some Brass and Bronze**  
**Wrought Alloys**

Alloy group	UNS designation	Elemental composition, wt% <sup>a</sup>
Zinc brass	C260	30 Zn
Leaded brass	C360	35 Zn, 3 Pb
Tin brass	C425	9.5 Zn, 2.0 Sn
Phosphor bronze	C510	5.0 Sn, 0.1 P
Aluminum bronze	C638	2.8 Al, 1.8 Si
Silicon bronze	C654	3.0 Si, 1.5 Sn, 0.1 Cr
Silicon bronze	C655	3.3 Si, 0.9 Mn
Modified Cu-Zn	C688	22.7 Zn, 3.4 Al, 0.4 Co

<sup>a</sup>Remaining percentage is copper.

The presence of finely dispersed second-phase particles in copper alloys contributes to strength, through refined grain size and increased response to hardening from cold working. A dispersion of fine particles can be incorporated into the alloy through thermomechanical processing where the alloy content is above the solid state solubility limit. Precipitation and coarsening of the excess solute by an in-process anneal is used in high copper alloys, such as C194 and C195, to form iron or iron-cobalt dispersions.

#### *Copper-Zinc (Cu-Zn) Brasses*

Copper-zinc alloys have been the most widely used of the copper alloys during the 1990's. Brass alloys fall within the designation C205 to C280 and cover the entire solid solution range up to 35 wt% zinc in the Cu-Zn alloy system. Zinc, which is generally less expensive than copper, does not impair conductivity and ductility to any appreciable extent. The alloys have a yellow "brass" color at zinc levels above 20 wt%. By far the best known and most used composition is the 30 wt% zinc alloy, called Cartridge brass, which is best known for its applications as door knobs and bullet cartridges.

The series of brasses, C312 to C385, contain from 0.25-5.0 wt% lead (Pb) for the purpose of improving machinability. C360, having the composition of 61.5 wt% copper, 35.4 wt% zinc, and 3.1 wt% lead, has become the industry standard for machinability performance.

### *Tin Brasses*

The tin brass series of alloys consists of various copper-zinc (2.5-35 wt%) alloys to which up to about 4 wt% tin has been added. These are the C40000 series of alloys. Tin provides better general corrosion resistance and strength without greatly reducing electrical conductivity. Several tin brasses have lead additions to enhance machinability. Naval Brass C485 contains 60.5 wt% copper, 37 wt% zinc, 0.7 wt% tin, and 1.8 wt% lead. Resistance to dezincification is increased with the addition of tin. In brasses that contain a high zinc content, it is common to use other alloying additives to enhance corrosion resistance. C443 contains 0.02-0.10 wt% arsenic, C444 contains 0.02-0.10 wt% antimony, and C445 contains 0.02-0.10 wt% phosphorus, which is added to control dezincification. When any of these elements are used, the alloy is referred as being “inhibited.”

### *Tin Bronzes*

Tin bronzes may be the most familiar of copper alloys with roots going back into ancient times. They are essentially solid solutions of tin in copper. Phosphorus at 0.03-0.35 wt% is commonly used as a deoxidizer, and the residual phosphorus content gives rise to the term “phosphor bronze.” The addition of tin to copper promotes good resistance to fresh and sea water. Under some conditions, when more than 5% tin is present, the corrosion resistance in marine applications is enhanced. Strength, corrosion resistance, and stress relaxation resistance increases with tin content. Where the water velocity is high, the tin content in copper alloys for marine applications should exceed 5%. Alloys containing between 8-10% tin have high resistance to impingement or erosion attack. Tin bronzes tend to have intermediate pitting resistance. One of the most highly used specialty tin bronzes is C544, containing 88 wt% copper-4 wt% tin-4 wt% zinc-4 wt% lead. Zinc provides increased strength to this tin bronze, whereas the lead addition provides good machinability.

### *Aluminum Bronzes*

Aluminum bronze alloys comprise a series of alloys (C606 to C644) based on the copper-aluminum (2-15 wt%) binary system, to which iron, nickel, and/or manganese are added to increase strength. Corrosion resistance results from the formation of an adherent aluminum oxide layer that protects the surface from further oxidation. Mechanical damage to the surface is readily healed by the redevelopment of this oxide. The aluminum bronzes are resistant to sulfuric or hydrochloric acids, but not nitric acid. These alloys must be properly heat treated to be resistant to dealloying and general corrosion.

Two single-phase, binary alloys are used commercially: C606, containing 5 wt% aluminum and C610, containing 8 wt% aluminum. Most of the available aluminum bronzes contain additional alloy elements. C608 contains 5 wt% aluminum to which 0.02-0.35 wt% arsenic has been added to improve corrosion resistance. Alloy C614, in addition to having 7 wt% aluminum and 2.5 wt% iron, also has a 0.3 wt% tin addition for improved resistance to stress corrosion.

Most of the aluminum bronzes contain substantial iron, nickel, or manganese additions. These alloying elements increase strength by forming second phases during heat treatment. Iron, the most commonly added element, separates as an iron-rich particle that controls grain size while it enhances strength. Nickel also reacts with aluminum to form NiAl precipitate during heat treatment with the same result as the iron addition.

### *Silicon Bronzes*

Silicon bronzes have long been available for use in electrical connectors, heat exchange tubes, and marine and pole line hardware because of their high solution hardened strength and resistance to general and stress corrosion. Their compositions are limited to below 4.0 wt% silicon because above this level, an extremely brittle phase is developed that prevents cold processing. The three most popular alloys in this series are C651, C654, and C655.

### *Modified Copper-Zinc Alloys*

The series of brass alloys C664 to C698 have been modified by additions of manganese (manganese brasses and manganese bronzes), aluminum, silicon, nickel, and cobalt. Each of the modifying additions provides some property improvement to the already workable, formable, and inexpensive Cu-Zn brass base alloy. Aluminum and silicon additions improve strength and corrosion resistance. Nickel and cobalt form aluminide precipitates for grain size control and dispersion strengthening by the presence of finely dispersed second-phase particles in the copper alloy.

### **Specific Properties of Cast Brass and Bronze Alloys**

Cast copper alloys can be classified into two main groups: single-phase alloys, characterized by moderate strength, high ductility (except for leaded varieties), moderate hardness and good impact strength; and polyphase alloys, having high strength, moderate ductility, and moderate impact strength. The tolerance for impurities is normally greater in cast copper alloys than in wrought copper alloy because the cast alloys are not mechanically formed. However, in those cast alloys likely to be repaired or joined by welding, some impurities can be very detrimental. On the basis of consumption, red brass alloys, C83600 (85 wt% copper, 5 wt% tin, 5 wt% lead, and 5 wt% zinc), C84400 (81 wt% copper, 3 wt% tin, 7 wt% lead, and 9 wt% zinc), and C93200 (83 wt% copper, 7 wt% tin, 7 wt% lead, and 3 wt% zinc) are the most important of the cast copper alloys.

The mechanical properties of cast copper alloys (e.g., brass, bronze) are a function of alloying elements and their concentrations. The nominal chemical composition and identification of some copper casting alloys are listed in Table A-4.

**Table A-4**  
**Nominal Composition by wt% of Some Casting Brass and Bronze Alloys**

Common name	UNS (CDA) designation	Cu	Sn	Pb	Zn	Fe	Al	Others
high strength yellow brass	C86300	63.0			25.0	3.0	6.0	3.0 Mn
gun metal	C 90500	88.0	10.0		2.0			
tin bronze 84:16	C 91100	84.0	16.0					
high leaded tin bronze	C 93700	80.0	10.0	10.0				
steam bronze	C 92200	88.0	6.0	1.5	4.5			
phosphorus bronze	C 94400	81.0	8.0	11.0				0.35 P
high leaded tin bronze	C 93800	78.0	7.0	15.0				
journal bronze	C 94100	70.0	5.5	18.0	3.0			
aluminum bronze 9D	C 95500	81.0				4.0	11.0	4.0 Ni
Al-Silicon bronze	C 95600	91.0					7.0	2.0 Si
Mn-Al bronze	C 95700	75.0				3.0	8.0	12.0 Mn, 2.0 Ni
Ni-Al bronze	C 95800	81.0				4.0	9.0	1.0 MN, 5.0 Ni
die-casting yellow brass	C 85800	58.0	1.0	1.0	40.0			
die-cast silicon brass	C 87800	82.0			14.0			4.0 Si
commercial no. 1 yellow brass	C 85400	67.0	1.0	3.0	29.0			
yellow brass	C 85700	63.0	1.0	1.0	34.7		0.3	
high strength yellow brass	C 86200	64.0			26.0	3.0	4.0	3.0 Mn
leaded high strength yellow brass	C 86400	59.0		1.0	40.0	2.0	1.5	1.5 Mn
silicon bronze	C 87200	89.0	1.0	0.5	5.0	2.5	1.5	1.5 Mn, 4.0 Si
silicon brass	C 87400	83.0			14.0			3.0 Si
silicon brass	C 87500	82.0			14.0			4.0 Si
tin bronze	C 90300	88.0	8.0		4.0			
leaded tin bronze	C 92300	87.0	8.0	1.0	4.0			
high leaded tin bronze	C 93200	83.0	7.0	7.0	3.0			
nickel-tin bronze	C 94700	88.0	5.0		2.0			5.0 Ni
leaded nickel-tin bronze	C 94800	87.0	5.0	1.0	2.5			5.0 Ni